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Tertiary Treatment for Safely Treated Wastewater Reuse

Nebil Belaid

Abstract

The tertiary treatment of resulting water from a conventional biological treatment process is envisaged in the aim to obtain a high quality of water that can be reused for different purposes. This treatment is based on the integration of the membrane-based technologies in the total process of wastewater treatment. The experimental studies are carried out on a small pilot, equipped with different mineral membranes of micro and ultrafiltration. These membranes are used for the different tested processes (MF, MF-UF and cogulation-MF). The results obtained make it possible to attend a complete elimination of the total flora and an additional reduction of the other parameters such as turbidity, suspended matter, COD and BOD. Tests on a large scale are then carried out on a semi-industrial pilot, equipped with the same type of membranes. The optimization of the operating conditions made allow the obtaining under the conditions of transmembrane pressure 0.85 bar, a cross flow velocity of 2.25m/s and with ambient temperature a filtrate flux of about 200 L/hm². The coupling of a stage of coagulation in the membrane process allows the reduction of the effect of the membrane fouling and an improvement of 36% of the filtrate flux.

Keywords: treated wastewater, tertiary treatment, microfiltration, ultrafiltration, reuse

1. Introduction

Population growth and economic development are putting pressure on water resources, especially in arid regions. Indeed, most MENA countries will have annual renewable water resources of less than 1000 m³/capita by the year 2025, according to estimates and projections of country-based populations and annual renewable water resources [1]. Moreover, the majority of MENA countries were classified as having a water deficit in 2010 (less than 500 m³/capita) [1]. Consequently, there is a need for new non-conventional water resources, such as water desalination, wastewater and rain harvesting, to meet the increasing demand. Wastewater reuse is gaining increasing attention for groundwater recharge and irrigation, since agriculture is the dominant water user in the region [2, 3].

Indeed, wastewater reuse for irrigation offers some attractive environmental and socioeconomic benefits [4–6]. In fact, the irrigation with treated wastewater leads to supply nutrients as fertilizer [7] as well as improvement crop production during the dry season [8, 9]. However, planners are aware of the potential disadvantages of wastewater reuse for irrigation which are, aside from pathogenic contamination

of irrigated crops, mainly related to their specific chemical composition being somewhat different from most natural waters used in irrigation [10]. Wastewater generally contains high concentrations of suspended and dissolved solids, both organic and inorganic (e.g. chloride, sodium, boron and selected heavy metals), that are added to wastewater during domestic and industrial usage [11]. Most of the salts added are only partially removed during conventional sewage treatment (secondary and tertiary), so they remain in the irrigation water [12]. Its content of trace elements, pathogens and high nitrogen may present a risk to the receiving environment. Additional treatment, particularly at the microbiological level, therefore appears necessary to ensure both user safety and reduce the impact on the receiving environment [13]. In this regard, membrane processes appear very promising for the complementary treatment of treated wastewater (TWW) [14]. Indeed, there is growing interest in direct filtration of wastewater treatment process for water reclamation to ease global water shortages [15–19]. Nowadays, integrated membrane systems treatment is becoming widely popular due to its feasibility, process reliability, commercial availability, relative insensitivity in case of wastewater treatment and lower operating costs [20]. Especially, direct filtration using ceramic membrane has been considered as an attractive option due to properties of ceramic membrane (e.g. a high durability and a high chemical resistance) [21–23].

In Tunisia, the reuse of treated wastewater (mainly secondary treated wastewater) for agricultural purpose is restricted for forages crops irrigation only. In Sfax (center east of Tunisia) where the average annual potential evaporation of 1200 mm, combined with the low rainfall and high temperatures, irrigation proves to be essential for crop production. Therefore, the treated wastewater has been used for forages irrigation since 1989. This practice had led to soil fertility improvement [24]. By contrast, an increase of soil salinity [25] and metallic elements accumulation has been detected [26]. In order to minimize health and environmental risks and for unrestricted irrigation reuse, the final treated wastewater quality should be improved.

The aim of this work is to study the feasibility of membrane techniques application, in particular microfiltration and ultrafiltration, for the tertiary treatment of the treated wastewater. Our study involves qualitative optimization trials, to define the appropriate treatment process. Three methods were tested, MF alone, MF-UF coupling and coagulation-MF coupling. Other tests to optimize the operating conditions and permeate flow are carried out, to evaluate the selected membrane process.

2. Materials and methods

2.1 Effluent origin

The treated wastewater is collected at the outlet of the Wastewater treatment plant (WWTP) of Mahrès (40 km south of the city of Sfax) which mainly treats domestic wastewater. Samples are collected during the period from January to May. After each companion, part of the sample is stored at -4°C for characterization. The WWTP of Mahrès treats the urban wastewater of the city and that of the Chafar seaside area. It is designed for a capacity of 13,000 equivalent inhabitants, which corresponds to a daily flow of $780\text{ m}^3/\text{day}$. The average daily flow was $800\text{ m}^3/\text{day}$ with peak flow rates exceeding $1400\text{ m}^3/\text{day}$, especially in summer. The station treatment process includes pretreatment (grit screening), biological treatment with activated sludge in an oxidation channel. A settling basin and sludge treatment (thickening, de-watering). The treated wastewater is, at the end, rejected in the sea.

2.2 Experimental methods and setups

2.2.1 Conduct of membrane filtration tests

Filtration is a physical process that involves the separation (removal) of a particulate and colloidal matter from a liquid. Indeed, membranes serve as selective barriers that allow the passage of some constituents and retain others. Based on pore size, shape and chemical/physical properties, membranes can separate different particles, organisms and chemical species. In this study, the conduct of the tests is based on determining the efficiency of two membranes processes, microfiltration (MF) and ultrafiltration (UF), for the removal of residual pollutants of secondary treated wastewater. Two aspects have been developed, one qualitative (final quality of the treated water) and the other one is quantitative (density of the permeate flow).

2.2.1.1 Qualitative filtration tests

In filtration process, the quality of treated water, permeate, depends on initial effluent quality and membranes properties. While, the quantity of produced permeate depends mainly of operating conditions.

In the first part of filtration tests the objective is to find the best permeate quality in terms of physic-chemical and biological properties. Thus, different membranes processes were tested (**Figure 1**):

- MF only: one single stage of microfiltration (0.2 μm) is performed to the effluent.
- MF-UF coupling: this process is composed by two stages. The effluent is filtered firstly, by a microfiltration membrane (0.2 μm) and secondly by an ultrafiltration one (15 KDa).
- Coagulation-MF coupling: after coagulation and settling, the effluent is then filtered by a microfiltration membrane (0.2 μm).

A small pilot scale “Kerasesp” was used during the experiments (**Figure 2**). The system is equipped by different ceramic membranes modules. These ones have a nominal surface area of 370 cm^2 and 400 mm of length (**Table 1**). This driver is easy to handle and allows operation on small volumes. Indeed, about 3 L of effluent were used for each filtration test. The operating parameters (pressure and frequency of pump rotation) are set at random. After each test, a characterization of the permeate is carried out.

2.2.1.2 Quantitative filtration tests

Once the best process is chosen, the operating conditions must be optimized. In fact, the best conditions give the maximum of permeate quantity with the least energy (low pressure).

The optimizing of operating conditions is carried out on a semi-industrial “Kerasesp” pilot (**Figure 3**). The membranes modules of this system have a nominal surface area of 800 cm^2 and 865 mm of length (**Table 1**). In this pilot, all operating parameters are controlled (transmembrane pressure, circulation speed and temperature). Thus, a 50 L of effluent is filtered through membrane module at fixed

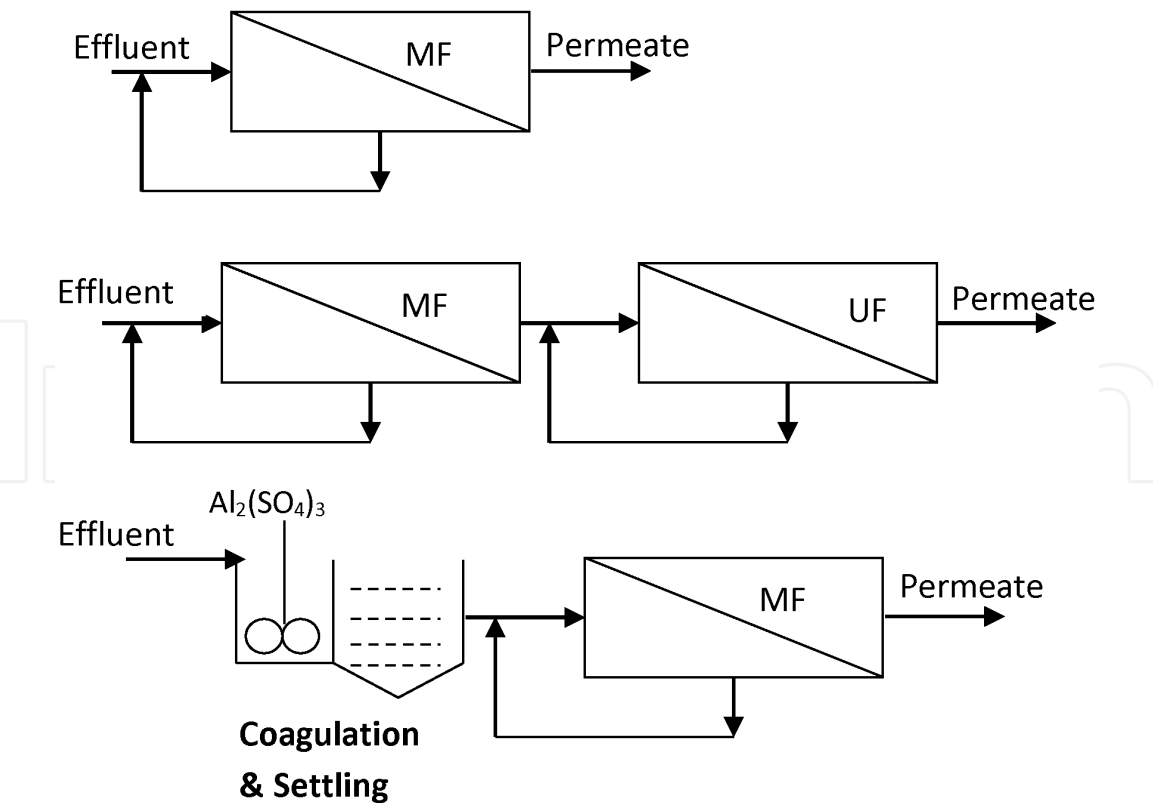


Figure 1.
Experimental design of tested processes.

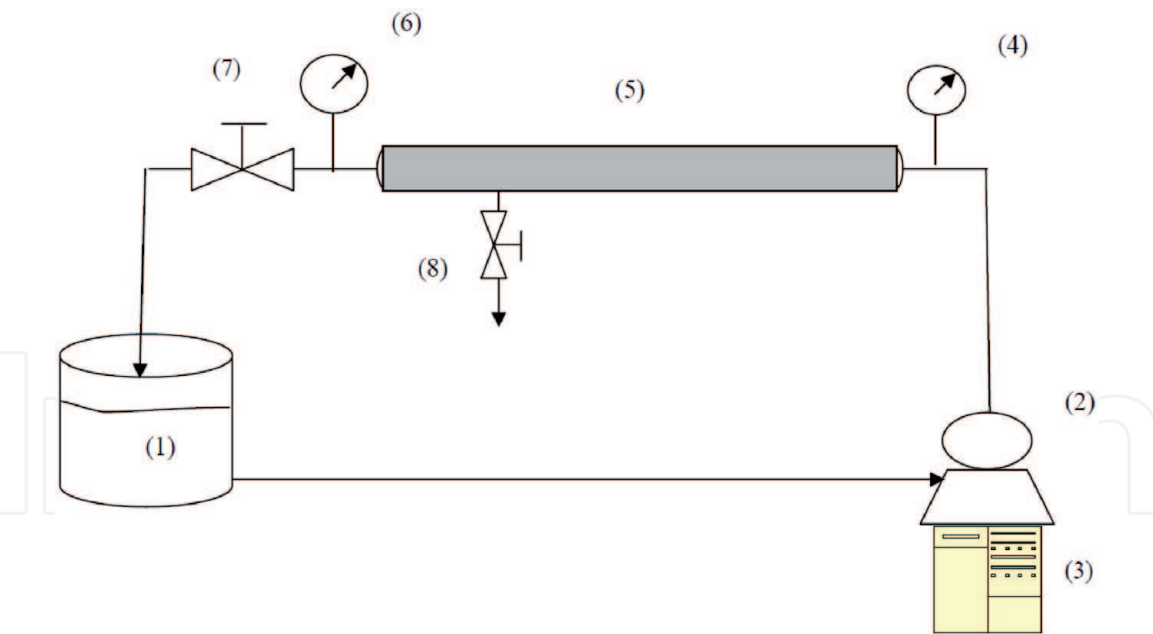


Figure 2.
Experimental small scale pilot. (1) effluent tank; (2) volumetric pump with adjustable frequency; (3) control block; (4) inlet pressure gauge; (5) membrane module; (6) outlet pressure gauge; (7) pressure valve adjustment; (8) permeate.

condition. This operation is repeated many times until reaching the best operating condition. Indeed, this optimization goes through two stages:

- The search for optimal conditions by varying the circulation speed (U) and the transmembrane pressure (TMP). For a given circulation speed (U), the PTM is varied and the permeate flow is measured. The plotting of the permeate flow

Characteristics	MF membranes		UF membrane
Average pore diameters	0.1 µm	0.2 µm	15 KDa
Length (mm)	865	400	400
Diameter (mm)	20	20	20
Surface area (cm2)	800	370	370
Number of channels	7	7	7
Diameter of canals (mm)	4.5	4.5	4.5

Table 1.
Specification of the used membranes.

curves as a function of circulation speeds and transmembrane pressures makes it possible to choose the best operating conditions.

- Monitoring the evolution of the permeate flow and the volume reduction factor (VRF) as a function of time, makes it possible to identify the nature and state of the membrane clogging.

The VRF is calculated as follows:
$$\frac{V_i - V_p}{V_p}$$

with

V_i : initial volume of the effluent

V_p : permeate volume

2.2.2 Membranes characteristics and cleaning procedure

The tubular membranes used are of the mineral type made of monolithic ceramic. They are consisted of an aluminum oxide support and a titanium oxide filtration layer. These characteristics facilitate effective cleaning with acidic or alkali solutions. The specifications of the different membranes used are shown in the **Table 1**.

The membrane and module cleaning protocol is most often provided by the manufacturer. However, this protocol has been modified to making it adapted to the nature of the effluent treated in this work. **Table 2** summarizes the adapted procedure.

2.3 Characterization of TWW

Treated effluents were sampled at the outlet of the Mahres wastewater treatment plant at different times and conserved at -4°C before characterization. Effluent samples were analyzed for pH and electrical conductivity using a pH meter [27] (AFNOR standard method N° NF T 90-008, see AFNOR, 1997) and a conductimeter (AFNOR N° NF EN 27888) respectively. Chemical oxygen demand (COD), suspended solids (SS), biochemical oxygen demand (BOD) and total phosphorus were measured according to standard methods (AFNOR N° NF T 90-018, NF EN 872, NF T 90-103, NF EN 1189). Cations and anions were measured using ion chromatography and trace metals by using Furnace Atomic Absorption

Spectrometry after aqua regia acid digestion (AFNOR N°NF EN ISO 15587-1). Carbonates and bicarbonates were estimated by titration with HCl of an aliquot of the effluent samples (AFNOR N° NF EN ISO 9963-2). Turbidity was determined at 860 nm by using a spectrophotometer DR/4000 U. The apparent color was determined by transmittance between 400 and 700 nm with the same

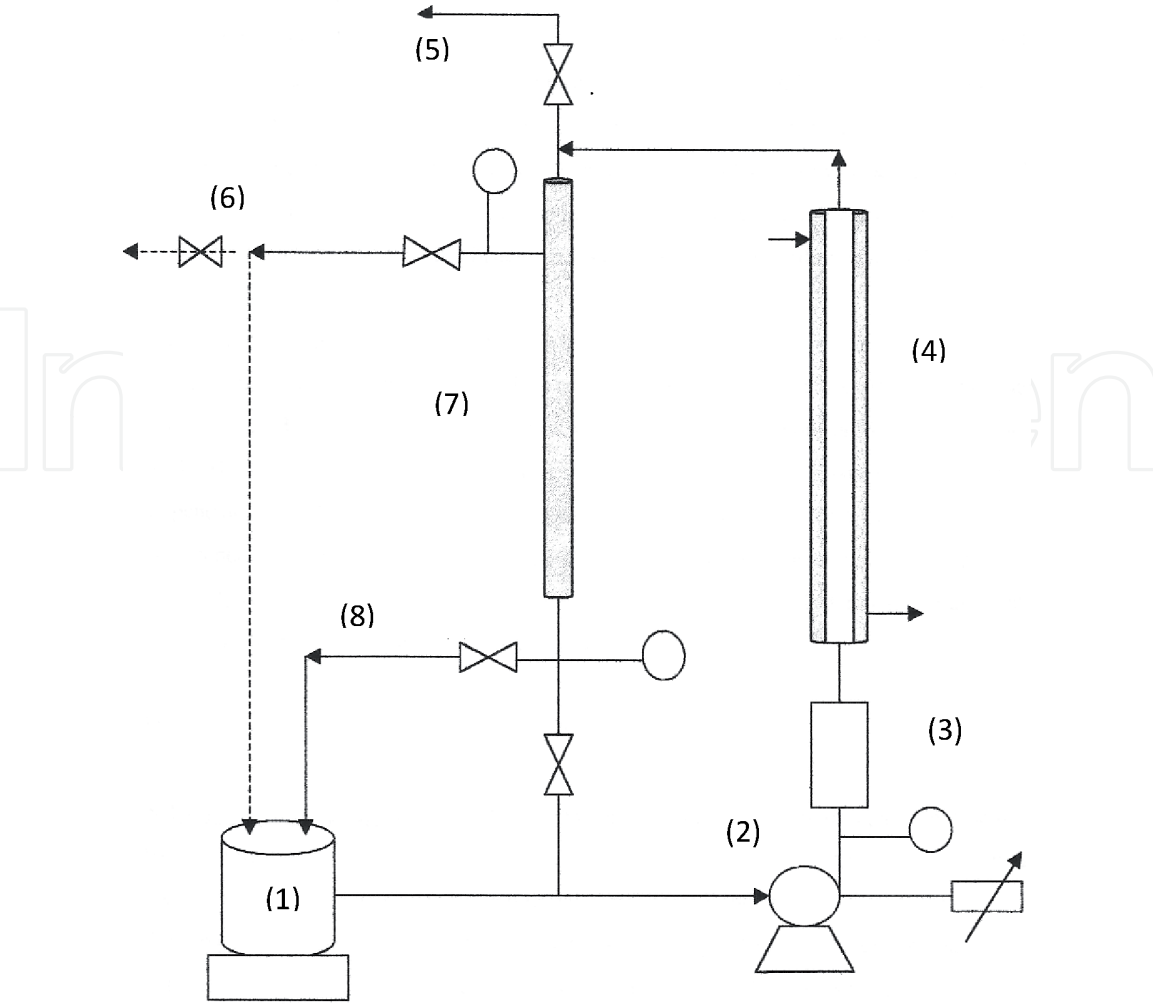


Figure 3. Experimental semi industrial pilot. (1) effluent thank; (2) volumetric pump with adjustable frequency; (3) flowmeter; (4) exchanger; (5) purge; (6) permeate; (7) membrane module; (8) Retentate.

Rinsing steps	Reagents	T (C °)	Duration (min)	P (bar)
Rinsing/draining	water	—	—	1
Basic wash with recycling	NaOH (10 g/L)	80–85	60	3–4
Rinsing until neutral	water	—	—	2–3
Acid wash with recycling	HNO3 (5 ml/L)	55–60	30	3–4
Rinsing until neutral	water	—	—	2–3
Water flow	water	—	10	2–4

Table 2. Membranes cleaning procedure.

spectrophotometer. The count of the total flora is carried out on Plate Count Agar (PCA) medium by inoculation on the surface and incubation at 37° C for 24 hours.

3. Results

3.1 Treated wastewater quality

The WWTP of Mahrès mainly receives and treats domestic wastewater. The quality of this water remains generally stable throughout the year except during

the summer period which corresponds to an increase in the affluent flow. The results obtained show that the temperature and the pH of the water, leaving the station, increase from January to May (**Table 3**). The treated wastewater always remained alkaline with an average pH of 7.5. The mean electrical conductivity (EC) of the effluents reached $4.27 \text{ mS}\cdot\text{cm}^{-1}$, which places the TWW in the class of high salinity according to the FAO legislation. The elevated EC values of the studied effluent are mainly explained by the abundance of free ions such as Na^+ , Cl^- and SO_4^{2-} which exceed the standards (**Table 3**). Turbidity and SS drop after January. The COD and the BOD are slightly elevated compared to the standards of discharges into nature. Moreover, TWW also contain large amounts of nitrate, phosphate and potassium, which are crucial nutrients for plant growth and soil fertility whatever this water is reused for irrigation. However, excepting Cr concentrations, the heavy metal contents are low. Whereas, the values of the total flora are high (**Table 3**).

Parameters	Effluent	Standards*
Temperature, °C	15–23	< 25 °C
pH	7.25–7.84	6.5 < pH < 8.5
CE, mS/cm	3.6–4.27	
Turbidity, NTU	1–141	
TDS, g/l	1.51–2.13	
Color, ADMI	26–32	70
SS, mg/l	3–121	30
COD, mg/L	115–231	90
BOD, mg/L	30–50	30
NH_4^+ , mg/L	16	1
NO_3^- , mg/L	15–24	50
P total, mg/L	1.07–6.7	0.05
Cl^- , mg/L	572–693	600
SO_4^{2-} , mg/L	646–844	600
HCO_3^- , mg/L	335–433	
Na^+ , mg/L	434–538	500
Mg^{2+} , mg/L	60–66	200
K^+ , mg/L	21–59	50
Ca^{2+} , mg/L	183–253	500
Cd, mg/L	0.02	0.005
Cr, mg/L	0.12	0.01
Cu, mg/L	0.04	0.5
Fe, mg/L	1.14	1
Zn, mg/L	6.5	5
Ni, mg/L	< 0,008	0.2
Total flora, ufc/mL	1.610^6 – 610^6	—

*Tunisian standards for irrigation reuse NT 106.03.

Table 3.
Treated wastewater quality.

By referring to the discharge standards (**Table 3**), a gradual improvement in the physicochemical parameters of the water during the study period is observed. In fact, the high values of turbidity and SS observed during the January campaign were subsequently greatly reduced. This can be attributed to the appearance of the phenomenon of bulking (expansion of sludge) in the station during the month of January and its disappearance thereafter. The effluent remains difficult to biodegrade since the BOD/COD ratio is usually less than 0.3. The heavy metal contents are low, which leads to the conclusion that there are no industrial discharges in the station. Thus, if the physical and chemical qualities of the treated wastewater are generally close to the standards, the biological quality still remains high. Tertiary treatment could then complete the treatment process and leads to water quality that meets all the requirements.

3.2 Tertiary treatment

The improvement of the final quality of the effluent and in particular the biological quality is studied by applying membrane processes. Two axes are developed. First, improving the final water quality by testing different processes. Then, define the operating conditions which ensure the best flow of permeate.

3.2.1 Qualitative study

3.2.1.1 MF-UF coupling

The process is composed by two-stage (**Figure 1**). In the first, the effluent undergoes microfiltration with recovery of the permeate which is then treated in a second stage by ultrafiltration. Two tests were carried out for this process using each time different microfiltration membranes.

During the first test, microfiltration and ultrafiltration are carried out on a bench-top pilot equipped with membranes of pore size $0.1\ \mu\text{m}$ and 15 KDa respectively. The main results obtained as well as the retention efficiency (RE) are reported in the **Table 4**.

Qualitatively, the first treatment with MF leads to an elimination of more than 90% of the turbidity and the SS. The COD and the BOD are also reduced to values lower than those of the Tunisian standard of discharge in the receiving environment (respectively 90 and 30 mg/L). After the second treatment with UF, most of the parameters analyzed undergo an additional reduction (**Table 4**). Moreover, UF is more suitable for removal COD particles [7]. For this test the analysis of biological parameters was not performed.

The evolution of the permeate flow during the filtration test shows that the flows are lower in MF than those obtained after MF-UF. Indeed, the values obtained are respectively in the order of 25L/h m^2 and 150 L/h m^2 (**Figure 4**). In fact, the decrease of the permeate flux to more than the half during the first 20 minute of the filtration is caused by the clogging phenomenon of the membrane due to the colloidal fraction in the effluent. In addition, the importance of membrane fouling leads to the drop of MF flow to a relatively low value at the end of experiment. However, in the second step of UF; the permeate flux is higher despite the small size of membrane pores. In fact, the majority of particles and colloids have been already eliminated after the first step of MF.

In order to improve the permeate flux of the first microfiltration step, a membrane of greater porosity ($0.2\ \mu\text{m}$) was used during a second test of the MF-UF coupling, while keeping the same characteristics of the UF membrane of the second stage. During this test, complete elimination of turbidity, MES and total

Parameters	Effluent	MF	RE (%)	MF-UF	RE (%)
pH	7.25	7.48	—	7.76	—
Turbidity, NTU	141	7	95	5	96.5
SS, mg/L	121	9	92.5	4	96
Color, ADMI	29	22	24	20	31
COD, mg/L	231	60	74	25	89
BOD, mg/L	40	10	75	10	75
P total, mg/L	5.16	3.99	22.5	3.45	33
Total flora, ufc/mL	610 ⁶	0	100	0	100

RE: retention efficiency.

Table 4.
Treated wastewater quality after MF and MF-UF treatment.

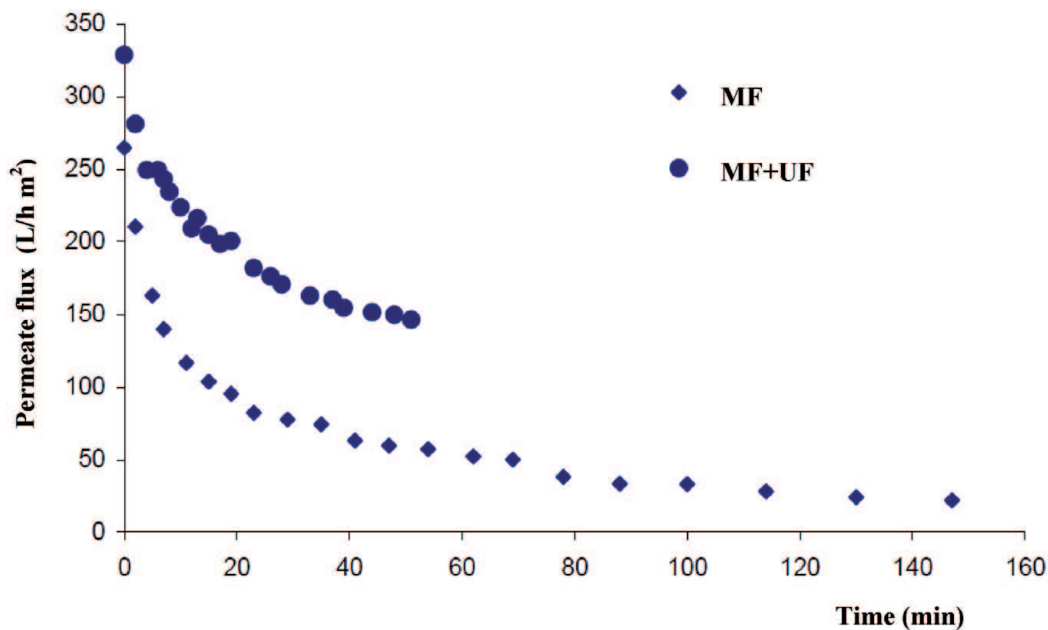


Figure 4.
Permeate flux decline for MF (0.1 μm) step and MF-UF step (small scale pilot).

flora was observed. However, the reduction in COD was lower, not exceeding 40%. The existence of small organic particles, not filtered, may be the cause of the low reduction in COD. However, a significant improvement in the permeate flux of the MF was observed. Thus, stabilized flow rates of around 90 L/h m² are obtained. In the second stage of UF, the same performance of the previous test is obtained, ie a stabilized flow rate of around 150 L/h m² (**Figure 5**).

Likewise, significant clogging of the first stage MF membrane was observed. In order to limit the consequences of this problem, an additional pre-treatment step appears essential.

3.2.1.2 Coagulation-MF coupling

In this process, microfiltration was preceded by coagulation pretreatment (**Figure 1**). Alumina sulfate is chosen as the coagulant.

In order to optimize the dose of used coagulant, varying amounts of alumina sulfate are added (between 20 and 100 mg/L). Stirring is performed with a Jar Test.

After settling, COD measurements are taken. The best reduction in COD is obtained with a dose of 40 mg/L (**Figure 6**).

Indeed, a dose of 40 mg/L of coagulant was added to the raw effluent. After stirring and settling for 24 hours, the water is microfiltered through a 0.2 μm membrane. This coagulation pretreatment has led to an improved of turbidity and a 35% reduction of COD value (**Table 5**). After MF, a reduction in SS, color and BOD values is observed with retention efficiency of 76%, 31% and 75% respectively.

3.2.2 Comparative study of the different processes

The quality of the different treated water from the various processes tested is compared to the initial quality of the effluents as well as to Tunisian standards for reuse in irrigation (**Table 6**).

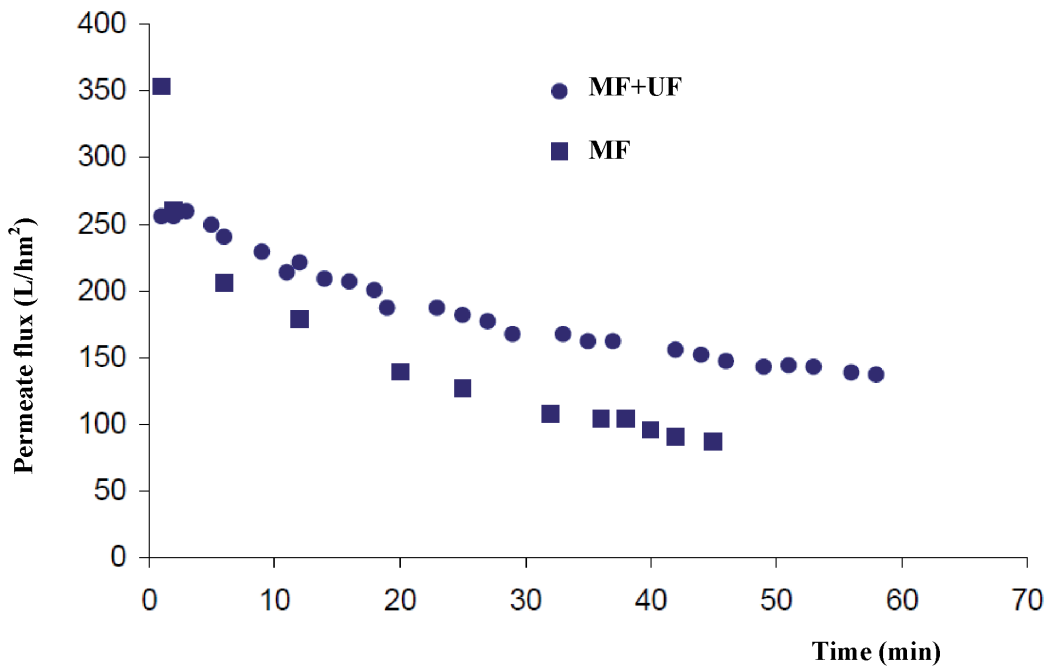


Figure 5.
Permeate flux decline for MF (0.2 μm) step and MF-UF step (small scale pilot).

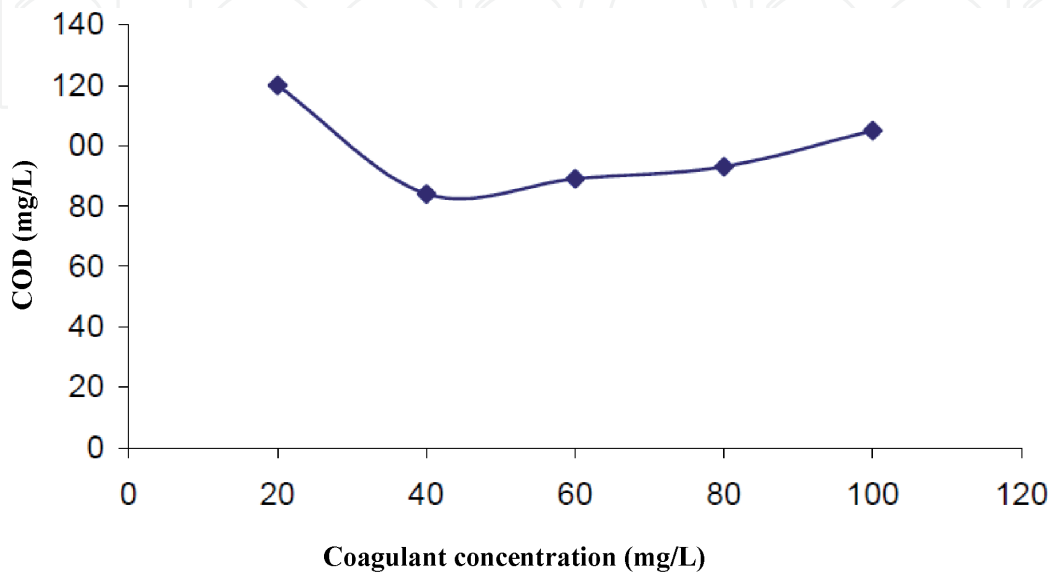


Figure 6.
Optimization of coagulant dose.

Parameters	Effluent	Coagulation	RE %	Coag + MF	RE %
Turbidity, NTU	2	0	100	0	100
MES, mg/L	8,5	8	6	2	76
Color, ADMI	32	31	4	22	31
COD, mg/L	124	80	35	58	53
BOD, mg/L	50	30	25	10	75

RE: retention efficiency.

Table 5.
Treated wastewater quality after coagulation and coagulation-MF treatment.

Parameters	Effluent	MF	MF-UF	Coag + MF	Standards [*]
pH	7.25–7.84	7.48–8	7.76–8.42	7.65	6.5–8.5
CE, mS/cm	3.6–4.27	3.02–4.05	3.1–4.38	3.68	7
Turbidity, NTU	1–141	0–7	0–5	0	—
TDS, g/L	1.51–2.13	1.51–2.02	1.55–2.18	1.84	
CoLo _r , ADMI	26–32	21–25	20–21	22	70
MES, mg/L	3–121	3–9	0–4	2	30
COD, mg/L	115–231	60–98	25–90	53	90
BOD mg/L	30–50	10–30	0–20	20	30
Nitrates, mg/L	15–24	5–27	5–33	28	—
P _{total} , mg/L	1.07–6.7	0.7–3.99	0.6–3.45	1.01	—
Cl [–] , mg/L	572–693	511–603	514–642	622	2000
SO ₄ ^{2–} , mg/L	646–844	604–726	615–724	764	—
HCO ₃ [–] , mg/L	335–433	335–372	331–360	354	—
Na ⁺ , mg/L	434–538	406–521	432–500	544	—
Mg ²⁺ , mg/L	60–66	60–66	45–58	75	—
K ⁺ , mg/L	22–59	17–47	17–27	19	—
Ca ²⁺ , mg/L	183–253	197–240	170–221	285	—
Cd, mg/L	0.02	< 0.004	<0.004	—	0.01
Cr, mg/L	0.12	0.08	0.05		0.1
Cu, mg/L	0.04	<0.01	< 0.01	—	0.5
Fe, mg/L	1.14	0.29	0.06	—	5
Zn, mg/L	6.5	0.03	0.02	—	5
Ni, mg/L	< 0.008	—	—	—	0.2
Total Flora, ufc/mL	1.6 10 ⁶ – 6 10 ⁶	0	0	0	—

^{*}Tunisian standards for irrigation reuse NT 106.03.

Table 6.
Quality of raw effluent and treated by the different processes.

Membrane techniques (MF and UF) do not have a great influence on EC and TDS. Their selectivity is far from stopping mono- and bivalent ions. However, they are effective in removing turbidity and SS. The use of these techniques also leads

to an improvement in color, especially after use of UF which provides effluent whitening [28].

In addition, more than 50% of COD and BOD are eliminated during water treatment by the various methods used. The ranges of variation of these values are quite wide and reflect the influence of the quality of the water to be treated on these two parameters. In particular, the residual COD values may reflect the existence of small particles that escape filtration [29]. In general, the final quality of the treated wastewater, whether by the membrane technique or by coagulation-MF coupling, meets Tunisian standards for agricultural irrigation (NT 106–03).

It was also found that the involvement of a membrane technique in the treatment process eliminates the total flora from the treated water. This is because the size of bacteria on the one hand and the clogging of the surface of the membranes used on the other hand combine to greatly reduce the passage of bacteria through the pores of the membranes. However, there can be easy contamination of treated water due to the presence of nutrients such as nitrates and phosphorus [15, 28].

The results obtained also make it possible to observe that there is a reduction in the concentrations of heavy metals in the treated water despite their low concentrations in the initial effluent. These results can be attributed not to the membrane technique used but rather to the retention of organic colloids with which metals are generally associated [14].

All the results obtained show that, despite the variation in the quality of the water collected at the outlet of the Mahrès station, additional treatment by membrane filtration allows the elimination of the total flora and the improvement of other physico-chemicals parameters. In fact, the use of microfiltration alone ensures good quality treated water, complying with standards and can be reused without restriction. On the other hand, the coupling of MF to UF or to coagulation rather has an effect on the quantity of treated water and not on the quality.

3.2.3 Quantitative study

The optimization of the operating parameters is carried out on a semi-industrial pilot equipped with the same type of membrane with a porosity of $0.1\ \mu\text{m}$ and a filtering surface of $800\ \text{cm}^2$. Two optimization trials were performed. The first is to do a single microfiltration step while a coagulation-MF coupling was tested in the second test.

The MF test is carried out with an initial volume of 20 L and under the following operating conditions: a transmembrane pressure TMP of 0.85 bar, a circulation speed U of 2.25 m/s and at room temperature. The initial flux is very high, around $800\ \text{L/hm}^2$ which, after 40 min, stabilizes at a value of $200\ \text{L/hm}^2$. The volume reduction factor (FRV) reaches a value of around 3.5, thus reducing the volume treated to 5.7 L.

For the second MF-coagulation test, 36 L of wastewater was pretreated by adding 40 mg/L of alumina sulfate. The supernatant is then microfiltered under the same operating conditions as the previous test. After 70 minutes, 31 liters of permeate are recovered which corresponds to an FRV of around 8.5. The stabilized permeate flux is approximately $200\ \text{L/hm}^2$ (**Figure 7**).

It appears that the coagulation step led to, on the one hand, reduce the major part of the colloids present in the raw effluent and on the other hand, to achieve very high FRV values. This coupling therefore results in an improvement in permeate flow of around 36% compared to MF alone (**Figure 7**). However, the introduction of this step in an overall sanitation process introduces two drawbacks, one relates to the use of coagulant and the other to the contact time required for this operation.

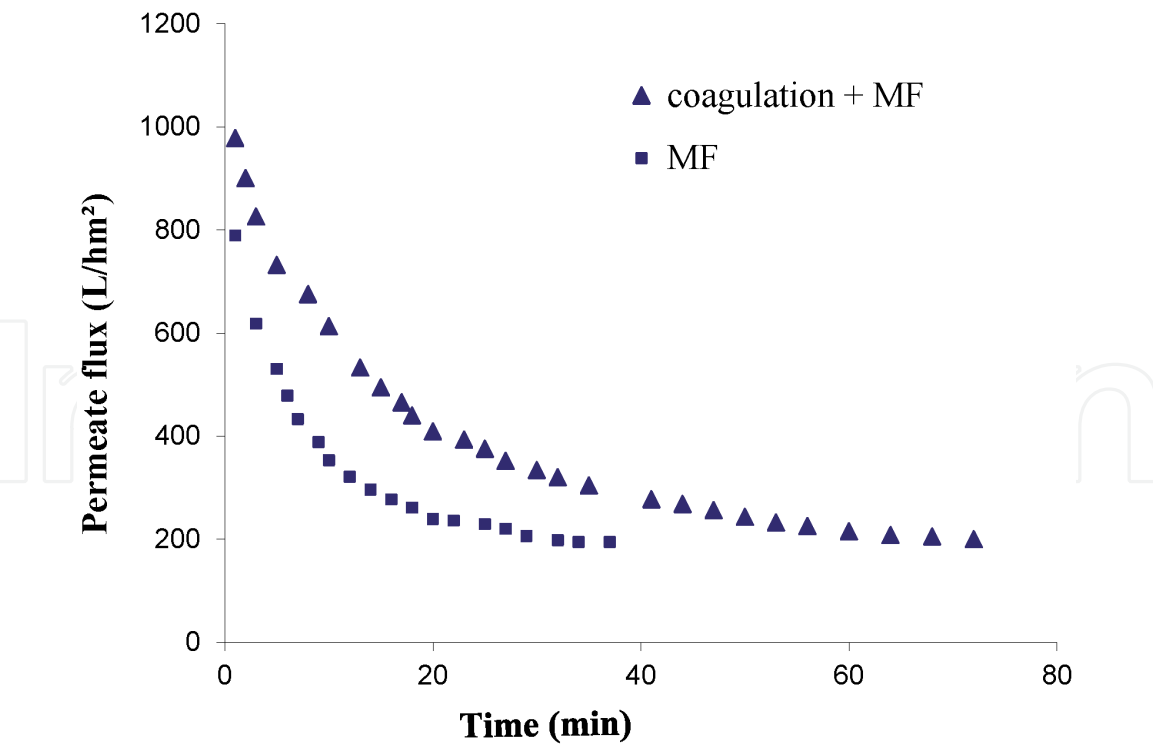


Figure 7.
Permeate flux decline for MF and coagulation-MF coupling (semi-industrial pilot).

It was also observed that during the coagulation-MF coupling, the unclogging of the membrane became easier than before. In fact, the membrane returns to its initial state, after a simple circulation of distilled water. Indeed, it was found that coagulation is the more efficient pretreatment before filtration processes [30–32]

4. Conclusion

The results obtained show that, despite the variation in the quality of the treated wastewater, additional treatment involving a membrane separation technique (MF) made it possible to eliminate the microbiological danger and the improvement of other parameters (biological and physicochemical). Coupling this technique with another process (coagulation or UF) does not lead to a significant improvement in the quality of the treated water. However, such a coupling can have an influence on the amount of water to be treated. Indeed, the pretreatment with coagulation before microfiltration improves the permeate flow and decrease membrane fouling compared to MF alone.

The integration of this microfiltration step on the scale of the wastewater treatment plant makes it possible to increase the available reserves of good quality water and to widen the fields of their uses. In fact, the unrestricted reuse of this treated water for the irrigation of crops of high economic profitability makes it possible to amortize investment costs while guaranteeing the health security of farmers.

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References

- [1] Jeuland, M. : Challenges to wastewater reuse in the Middle East and North Africa. *Middle East development Journal*, 2015; 7-1. doi:10.1080/17938120.2015.1019293
- [2] Qadir M., Bahri A., Sato, T., Al-Karadsheh E. : Wastewater production, treatment, and irrigation in Middle East and North Africa. *Irrig Drainage Syst*, 2010, 24; 37-51. doi:10.1007/s10795-009-9081-y
- [3] Salgot M., Folch M.: Wastewater treatment and water reuse. *Current Opinion in Environmental Science & Health*, 2018, 2; 64-74. doi:10.1016/j.coesh.2018.03.005
- [4] Kam G., Ding C.: Wastewater Treatment and Reuse—The Future Source of Water Supply. *Encyclopedia of Sustainable Technologies*, 2017, 43-52. doi:10.1016/B978-0-12-409548-9.10170-8
- [5] Garcia X., Pargament D. : Reusing wastewater to cope with water scarcity: Economic, social and environmental considerations for decision-making. *Resources. Conservation and Recycling*, 2015, 101; 154-166. doi:10.1016/j.resconrec.2015.05.015
- [6] Alkhudhiri A., Darwish NB., Hilal N. : Analytical and Forecasting Study for Wastewater Treatment and Water Resources in Saudi Arabia. *J. Water Process Eng*. 2019, 32. doi:10.1016/j.jwpe.2019.100915
- [7] Oron G., Gillerman L., Bick A., Buriakovsky N., Manor Y., Ben-Yitshak E., Katz L., Hagin J. : A two stage membrane treatment of secondary effluent for unrestricted reuse and sustainable agricultural production. *Desalination*, 2006, 187; 335-345. doi:10.1016/j.desal.2005.04.092
- [8] Pescod M.B. :Wastewater treatment and use in agriculture. *Bull. FAO*, 1992, 47, Rome, Italy, 125 p.
- [9] Yadav RK, Goyal B., Sharma RK., Dubey SK., Minhas PS.: Post-irrigation impact of domestic sewage effluent on composition of soils, crops and groundwater - A case study. *Environ. Internat.*, 2002, 28;481-486. [https://doi.org/10.1016/S0160-4120\(02\)00070-3](https://doi.org/10.1016/S0160-4120(02)00070-3)
- [10] De Gisi S., Casella P., Cellamare CM., Ferraris M., Petta L., Notarnicola M. : Wastewater Reuse. *Encyclopedia of Sustainable Technologies*, 2017, 53-68. <https://doi.org/10.1016/B978-0-12-409548-9.10528-7>
- [11] Levine, A. and Asano T.: Recovering sustainable water from wastewater. *Environ. Sci. Technol.*, 2004, 38; 201A-208A. <https://doi.org/10.1021/es040504n>
- [12] Tarchitzky J., Golobati Y., Keren R., Chen Y.:Wastewater effects on montmorillonite suspensions and hydraulic properties of sandy soils. *Soil Sci. Soc. Am. J.*, 1999 63; 554-560. <https://doi.org/10.2136/sssaj1999.03615995006300030018x>
- [13] Vojtěchovská Šrámková M., Diaz-Sosa V., Wanner J. : Experimental verification of tertiary treatment process in achieving effluent quality required by wastewater reuse standards. *Journal of Water Process Engineering*, 2018, 22; 41-45. <https://doi.org/10.1016/j.jwpe.2018.01.003>
- [14] Wintgens T., Melin T., Schiller A., Khan S , Muston M., Bixio D. , Thoeve C. : The role of membrane processes in municipal wastewater reclamation and reuse. *Desalination*, 2005, 178; 1-11. <https://doi.org/10.1016/j.desal.2004.12.014>

- [15] Abdessemed, D., Nezzal, G.: Treatment of primary effluent by coagulation-adsorption-ultrafiltration for reuse. *Desalination*, 2002,152 ; 367-373. [https://doi.org/10.1016/S0011-9164\(02\)01085-8](https://doi.org/10.1016/S0011-9164(02)01085-8).
- [16] Abdessemed, D., Nezzal, G., Ben aim, R.: Treatment of wastewater by ultrafiltration. *Desalination*, 1999, 126; 1-5. [https://doi.org/10.1016/S0011-9164\(99\)00149-6](https://doi.org/10.1016/S0011-9164(99)00149-6).
- [17] Fujioka, T., Nghiem, L.D., Fouling control of a ceramic microfiltration membrane for direct sewer mining by backwashing with ozonated water. *Separ. Purif. Technol.*, 2015,142; 268-273. <https://doi.org/10.1016/j.seppur.2014.12.049>.
- [18] Gong, H., Jin, Z., Wang, X., Wang, K.: Membrane fouling controlled by coagulation/adsorption during direct sewage membrane filtration (DSMF) for organic matter concentration. *J. Environ. Sci. (China)*, 2015, 32 ; 1-7. <https://doi.org/10.1016/j.jes.2015.01.002>.
- [19] Makropoulos, C., Rozos, E., Tsoukalas, I., Plevri, A., Karakatsanis, G., Karagiannidis, L., Makri, E., Lioumis, C., Noutsopoulos, C., Mamais, D., Rippis, C., Lytras, E. : Sewer-mining: a water reuse option supporting circular economy, public service provision and entrepreneurship. *J. Environ. Manag.*, 2018, 216; 285-298. <https://doi.org/10.1016/j.jenvman.2017.07.026>.
- [20] Hakami M W., Alkhudhiri A. , Al-Batty S., Zacharof MP., Maddy J., Hilal N. : Ceramic Microfiltration Membranes in Wastewater Treatment: Filtration Behavior, Fouling and prevention. *Membranes*, 2020, 10; 248. <https://doi.org/10.3390/membranes10090248>
- [21] Shang, R., Verliefde, A.R.D., Hu, J., Zeng, Z., Lu, J., Kemperman, A.J.B., Deng, H., Nijmeijer, K., Heijman, S.G.J., Rietveld, L.C.: Tight ceramic UF membrane as RO pre-treatment: the role of electrostatic interactions on phosphate rejection. *Water Res.* 2014, 48; 498-507. <https://doi.org/10.1016/j.watres.2013.10.008>.
- [22] Weber, R., Chmiel, H., Mavrov, V.: Characteristics and application of new ceramic nanofiltration membranes. *Desalination*, 2003, 157 ; 113-125. [https://doi.org/10.1016/S0011-9164\(03\)00390-4](https://doi.org/10.1016/S0011-9164(03)00390-4).
- [23] Fane AG.: Sustainability and membrane processing of wastewater for reuse. *Desalination*, 2007;202: 53-58. <https://doi.org/10.1016/j.desal.2005.12.038>
- [24] Belaid N., Neel C., Kallel M., Ayoub T., Ayadi A. and Baudu M.: Long term effects of treated wastewater irrigation on calcisol fertility: A case study of Sfax-Tunisia. *Agricultural Sciences*, 2012, 3(5); 702-713. <http://dx.doi.org/10.4236/as.2012.35085>
- [25] Belaid N., Neel C., Kallel M., Ayoub T., Ayadi A., Baudu M.: Effects of treated wastewater irrigation on soil salinity and sodicity of Sfax (Tunisia): A case study. *Journal of Water Science*. 2010, 23(2); 133-145. <https://doi.org/10.7202/039905ar>
- [26] Belaid N., Neel C., Lenain JF., Buzier R., Kallel M., Ayoub T., Ayadi A. Baudu M.: Assessment of metal accumulation in calcareous soil and forage crops subjected to long-term irrigation using treated wastewater: Case of El Hajeb-Sfax, Tunisia. *Agriculture, Ecosystems & Environment*, 2012, 158(1); 83-93. <https://doi.org/10.1016/j.agee.2012.06.002>
- [27] AFNOR, Evaluation de la qualité des sols, vol. 1. AFNOR Editions, 2004, Paris; p 461
- [28] Alonso E., Santos A., Solis GJ., Riesco P. : On the feasibility of urban

wastewater tertiary treatment by membranes: a comparative assessment. Desalination, 2001, 141; 39-51. [https://doi.org/10.1016/S0011-9164\(01\)00387-3](https://doi.org/10.1016/S0011-9164(01)00387-3)

[29] Ahn KH. and Song KG. : Treatment of domestic wastewater using microfiltration for reuse of wastewater. Desalination, 1999; 126: 7-14. [https://doi.org/10.1016/S0011-9164\(99\)00150-2](https://doi.org/10.1016/S0011-9164(99)00150-2)

[30] Im D., Nakada N., Kato Y., Aoki M., Tanaka H.: Pretreatment of ceramic membrane microfiltration in wastewater reuse: A comparison between ozonation and coagulation. Journal of Environmental Management, 2019, 251: 109555. <https://doi.org/10.1016/j.jenvman.2019.109555>

[31] Fan L., Nguyen T., Roddick FA., John L. Harris JL. : Low-pressure membrane filtration of secondary effluent in water reuse: Pre-treatment for fouling reduction. Journal of Membrane Science, 2008; 320: 135-142. <https://doi.org/10.1016/j.memsci.2008.03.058>

[32] Hatt JW., Germain E., Judd SJ.: Precoagulation-microfiltration for wastewater reuse. Water Research, 2011, 45; 6471-6478. <https://doi.org/10.1016/j.watres.2011.09.039>